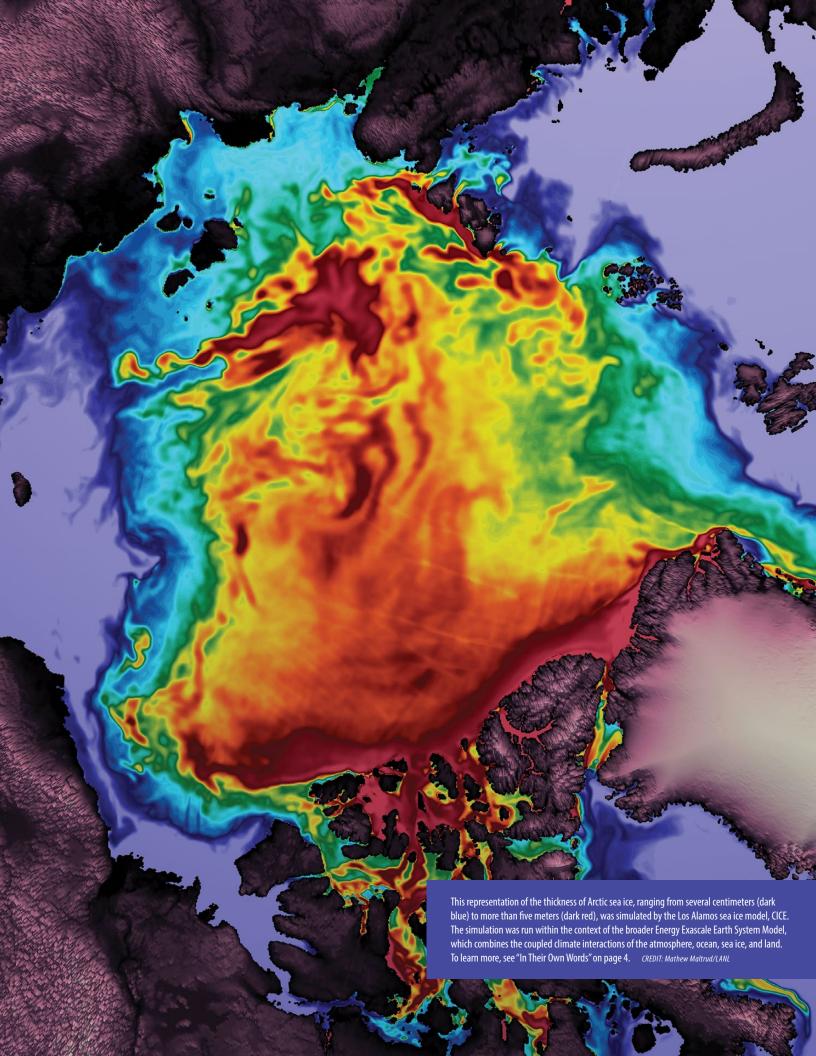
Chasing beauty quarks Reduce-reuse-recycle for plutonium Modeling sea ice with CICE Ultrasound goes underground Frost-resistant farming

SPACE SHRAPNEL

Satellite overcrowding and the growing threat from orbiting debris





1663

LOS ALAMOS SCIENCE AND TECHNOLOGY MAGAZINE

ABOUT THE COVER

The "Kessler effect" describes a runaway series of satellite collisions. One collision produces a spray of high-speed orbiting shrapnel, some of which then collides with other satellites and produces more shrapnel, until low earth orbit is effectively unusable. The first major collision of this sort took place in 2009 and spawned more than 2000 pieces of debris. Meanwhile, new satellites are being launched at a breakneck pace. increasing orbital overcrowding and potentially hastening the next collision. Los Alamos is trying to head off disaster: Lab scientists have developed a promising new technology for space-traffic management that relies on ultralow-power transmitters on satellites and ultrasensitive receivers on the ground, effectively tagging satellites for monitoring—and, when needed, course corrections—the way a license plate tags a car.

ABOUT OUR NAME

During World War II, all that the outside world knew of Los Alamos and its top-secret laboratory was the mailing address—P. O. Box 1663, Santa Fe, New Mexico. That box number, still part of our address, symbolizes our historic role in the nation's service.

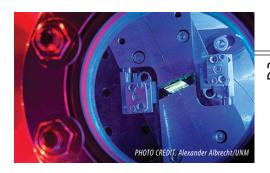
ABOUT THE LORD LOGO

Laboratory Directed Research and Development (LDRD) is a competitive internal program by which Los Alamos National Laboratory is authorized by Congress to invest in research and development that is both highly innovative and vital to national interests. Whenever 1663 reports on research that received support from LDRD, this logo appears at the end of the article

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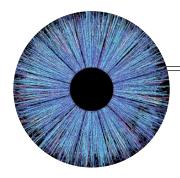


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New instrument will see the world at the quark level

CREDIT: Brookhaven National Laboratory

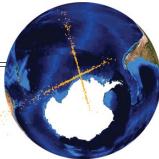


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CREDIT: Rlandmann/Wikipedia, Astronautics Research Group, University of Southampton



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Los Alamos helps local farmers adapt to changes in the growing season

SPOTLIGHTS

OPTICS

Lasers Are Cool and Cooling

Breakthrough laser-driven crystal cryocooler with no moving parts

Compared to heating, cooling is notoriously difficult and inefficient. It typically involves compressing and circulating a specialized refrigerant that draws heat away from one region and dumps it somewhere else (e.g., behind the fridge). The whole endeavor remains curiously old-fashioned, with all the groaning noise and rattling vibration one might expect from a process that essentially operates by 19th century plumbing.

However, in cutting-edge laboratory science, or in remote locations, such as onboard a spacecraft, rumbling plumbing just won't cut it: the noise and vibration interfere with sensitive systems. Even in the most advanced cryocoolers, moving parts remain a significant drawback. Now, for the first time, moving parts are no longer necessary.

A research collaboration between Los Alamos and the University of New Mexico, led by Los Alamos scientist Markus Hehlen, recently unveiled a breakthrough in cooling technology: an all-solid-state optical cryocooler with no moving parts. While not cost effective for everyday consumer refrigeration, the new system offers tremendous benefit for advanced imaging and other applications.

The cryocooler takes advantage of anti-Stokes fluorescence, in which a material emits light at a slightly higher average energy than that of an exciting laser. To make up the difference, energy is withdrawn from heat within the material; it is essentially a laser running in reverse. Net cooling of a solid by anti-Stokes fluorescence was first observed in Los Alamos, in 1995.

Even though it was observed decades ago, using anti-Stokes fluorescence to create a practical cryocooling system has proven exceedingly difficult, requiring a combined absorption and quantum efficiency of 98 percent or more. That means the fluorescing material must be an extraordinarily pure crystal. The team was able to achieve this with an yttrium-lithium-fluoride (YLiF₄) crystal, in which about 10 percent of the yttrium ions (Y³+) were replaced (or "doped") with ytterbium ions (Yb³+). It is these Yb³+ ions that emit anti-Stokes fluorescence when excited by a laser at a 1020-nm wavelength, in the near infrared.

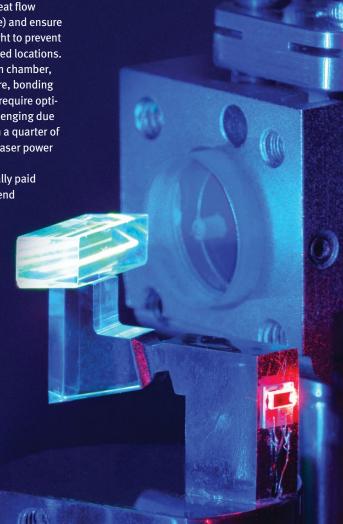
In addition to the crystal purity, the surrounding apparatus must be exquisitely designed to achieve the proper heat flow (conducting here, insulating there) and ensure the escape of the fluorescence light to prevent it from generating heat in undesired locations. The various components—vacuum chamber, mirrors, sensors, support structure, bonding agents, and optical coatings—all require optimization. This is particularly challenging due to the small crystal size (less than a quarter of a cubic centimeter) and the high laser power (50 watts or more) involved.

All that attention to detail finally paid off when the team cooled a high-end infrared sensor, such as might be

used on a telescope or a thermal-imaging satellite, to its desired operating temperature of –138 degrees Celsius, much colder than existing nonmechanical cryocoolers can handle. A big part of that success relied upon designing a specialized thermal link to attach the sensor to the cooling crystal without creating an insulating barrier between them or allowing the crystal's fluorescence to warm the sensor. (An adhesive mounting, for instance, would have failed on both counts.)

The research, which capitalized on a number of key Los Alamos specialties (such as optical technologies, crystal growth, and aerogels) and facilities (Target Fabrication Facility, Center for Integrated Nanotechnology, and advanced clean rooms), may prove transformative for a number of high-tech applications. For example, by eliminating mechanical jitter, the optical cryocooler could greatly improve image quality from

Experimental setup with cooling crystal (green) atop a specially designed L-shaped thermal link that draws heat from an infrared sensor (red) and its mounting, cooling the sensor to its operational temperature of —138 degrees Celsius. The crystal is being excited by an infrared laser beam and cools by fluorescing at a slightly higher infrared energy (both unseen); the green glow, which produces negligible heating, is due to an unrelated excitation of the element erbium, an impurity within the crystal. PHOTO CREDIT: Alexander Albrecht/UNM



ground- and space-based telescopes and high-magnification cryogenic electron microscopes without the need for ancillary systems to compensate for vibration. It also stands to upgrade a number of non-imaging applications, from improving the resolution of gamma-ray detectors to tightening the accuracy of atomic clocks.

Laser-driven crystal cooling can even revolutionize the laser itself. Upon demonstrating the new cryocooler, Hehlen and external collaborators immediately set to work on an important application: a self-cooling laser, in which the heat generated by the laser is exactly offset by the heat carried away by its own laser-crystal cooling. By eliminating thermal instabilities, such "radiation-balanced" lasers will be able to operate at much higher power. Cool. LDRD

-Craig Tyler

THREAT DETECTION

Security Through Signatures

Identifying chemicals through their atomic-level interactions

Some dangers are easily hidden in plain sight. Consider an unlabeled three-ounce bottle of clear liquid: it could be water, it could be rubbing alcohol, or it could be something more hazardous. Is it safe to be shipped through the mail? Or taken aboard an airplane? Certain chemicals can be toxic if released into the air, so somehow the bottle's contents need to be verified without removing the lid. Although current detection techniques are doing the job, recent advances in identifying chemicals by studying their atomic interactions could usher in a new level of scrutiny.

In 2010, Los Alamos physicist Michelle Espy and her team made headlines when they introduced a method of scanning travel bottles for liquid explosives using ultralowfield nuclear magnetic resonance (ULF-NMR). Nuclear magnetic resonance can be used to characterize atoms in molecules by measuring the response of their nuclei to a magnetic field. Although the two-step process was ultimately too slow for the impatient passenger queues at airport security, the team was onto something: small, portable, low-field magnets can be useful for detecting specific chemical compounds, and sometimes they can be even more useful than their high-field cousins.

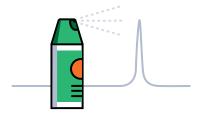
In traditional NMR, strong magnetic fields cause the nuclei of atoms to align with the field. Then, a weaker oscillating magnetic field is applied to search for a resonant response from the nuclei, which occurs at an oscillation frequency that's specific to the material being probed. Varying the strength of the primary (static) magnetic field can cause the nuclei to resonate at different frequencies depending on their exact chemical environment—a phenomenon referred to as chemical shift.



These patterns of resonances can be used to identify the atoms in chemical compounds, but at very low magnetic fields, the chemical shift disappears and the signals get lumped together in a very narrow frequency range. However, upon closer examination, Espy and colleague Bob Williams discovered that for some compounds, the frequency signals are actually quite distinctive.

"We found that molecules containing a few specific elements have a unique finger-print," says Espy. And the fingerprints they discovered are especially helpful. Using fertilizers, insecticides, and related materials as surrogates, Espy, Williams, and their colleagues have used ULF-NMR to rapidly (less than 8 seconds) identify the fingerprints of chemical-threat agents in TSA-approved travel bottles, as part of a project supported by the Department of Homeland Security's Science and Technology Directorate through an interagency agreement with Los Alamos.

These characteristic signals are caused by a phenomenon referred to as J-coupling, which happens when the nuclei of neighboring atoms in molecules begin to interact, or couple, with each other when the magnetic field is applied. For instance, one may expect a compound containing two hydrogen-carbon bonds to show two distinct hydrogen signal peaks, but if they are coupled, the peaks will instead split into four smaller ones. What's fascinating is that although high magnetic



fields can detect these unique J-coupled signatures, they are much richer at very low field—in fact, the lower the better.

"Using advanced electronics that are now available, we are able to see these interactions using only the earth's 50-microtesla magnetic field," says Williams, a bio-organic chemist. (A magnetic field of 50 microteslas is tens of thousands of times weaker than that used by a typical medical MRI machine.)

Williams explains that although J-coupling has been used for many years to determine chemical structures, it has never before been done with magnetic fields this low. Low fields mean smaller magnets and the potential for a whole new level of portable chemical detection. LDRD

—Rebecca McDonald



When chemical compounds are exposed to ultralow magnetic fields, the nuclei of specific elements can interact, causing the signal to split in a unique way. This phenomenon, called J-coupling, is being used to identify chemicals of interest.



Composing Sea Ice Stanzas

Climate scientist **Elizabeth Hunke** reflects on ice, music, and 25 years at Los Alamos.

I THOUGHT I WOULD BE A MUSICIAN.

I am, actually, a musician—I've played piano and brass instruments since I was in grade school. In high school I pursued music, science, and math somewhat equally, but after my first year of college I realized that if I majored in music it would become work, and my enjoyment of it might fizzle. Also, it would probably be more tenable to make a living doing math or science, keeping music as a hobby, than vice versa. So, I chose math.

I love the elegance of mathematics and its applications—it is a natural companion to both music and science. It also seemed like a reliable avenue into just about any scientific enterprise, so I could keep my interests diverse. I started my scientific career as an intern at AT&T Bell Laboratories working in molecular beam epitaxy, analyzing a molecular structure simulation for its potential electrical properties. I've since studied tornadoes and hurricanes, sea ice, and even the wildlife that lives on (or in) the ice. I continue to enjoy playing music with a handful of local ensembles, while building a career in science that has been varied, challenging, rewarding, and enormously fun. Throughout my career in climate science at Los Alamos, I've often appreciated the parallels and overlap between being a musician and being a scientist.

Melting sea ice affects how ocean water circulates. Here, Los Alamos climate scientist Elizabeth Hunke—wearing an heirloom parka made by her mother, who was an early and staunch supporter of Hunke's scientific, artistic, and adventurous pursuits—demonstrates the difference in how ice (with blue dye) melts into salt water (left) compared to fresh water (right). When sea water freezes to form sea ice, most of the salt drains into the water below. So when that ice melts, it forms a lightweight layer of fresher meltwater atop the salty seawater (left), capping the ocean and suppressing vertical, convective circulation. PHOTO CREDIT: Michael Pierce

Playing with a musical group can be deeply satisfying, as the musicians' independent sensibilities meet and meld to create something new and beautiful from essentially nothing. Just as staves of music notes describe rolling arpeggios of sound, stacks of mathematical formulae describe elaborate processes occurring in nature. Computers are our "instruments" in the modeling world, and while not everyone would consider a computer program beautiful, the complexity and elegance of mathematical modeling is, to me at least, both beautiful and satisfying.

From the tropics to the poles

Designing a mathematical model for a particular scientific phenomenon and then writing a computer program to solve it is, like making music, a creative process. It's also tremendously complicated for climate applications. Weather forecasting provides a good, everyday example of these kinds of models at work. A weather model combines data on changing temperatures, humidity, pressures, and wind, across different altitudes and through time, with a complex set

In graduate school, I spent a summer as an intern at Los Alamos, and my mentor from that time, Mac Hyman, remained a mentor throughout graduate school and indeed my whole career. When I began looking for a postdoctoral job, climate change was becoming a hot topic and Mac steered me toward it. The ocean modeling team wanted to develop a computationally efficient sea ice model that would be compatible with the Parallel Ocean Program, an ocean circulation model

Rapidly declining Arctic sea ice means more ships are attempting to get through, so the safety and economic stakes are ever higher. CICE predicts sea ice extent, thickness, and movement around polar oceans using data from atmosphere and ocean systems, in turn collected by buoys, ships, aircraft, and satellites. The latest update to CICE improves modeling of landfast ice, ice that is anchored to the shore or sea floor. Landfast ice can block shipping lanes and ports, even when the rest of the route is passable. Having an idea of when ice will form, melt, or drift out to sea helps mariners and coastal communities plan their activities wisely.

developed at Los Alamos in the early 1990s. The goal was to eventually create a fully coupled atmosphere-ice-ocean-land global climate model that would efficiently utilize the computational power offered by the new, massively parallel supercomputers becoming available at that time, using thousands of processors at once to solve intricate sets of mathematical equations.

Designing a mathematical model for a scientific phenomenon and writing a computer program to solve it are both creative processes.

of mathematical equations to make a prognostication about what is most likely to happen in the near future.

I came to Los Alamos 25 years ago, fresh out of graduate school, to join the ocean modeling team in the Theoretical Division. I had done my doctoral work on tropical cyclone modeling, having had my interest piqued by a professor who presented a simple mathematical model describing how hurricanes work. As with my early ideas of making a career in music, I thought hurricane modeling would be my life's work, and I hoped for the opportunity to fly into a hurricane aboard a research aircraft. But, although that opportunity never came, and although I could not have dreamed it at the time, I have since traveled to the ends of the earth doing polar research.

Sea ice and hurricanes seem like very different phenomena, but the equations used to describe them are actually quite similar, and it wasn't a huge leap for me to move into sea ice modeling. As I had anticipated, the mathematical knowledge and skills that I developed in graduate school translated easily to my new job as a sea ice modeler.

The impact of weather on humans has always been of interest to me. I spent some time as a child in Cordova, Alaska, with my father who was a Coast Guard officer in Prince Edward Sound. Even in elementary school, I was aware that the huge snowstorms in Cordova were a result of warm ocean currents bringing moisture to that area. Little did I know then how large a role the sea ice I saw in the harbor would play in my later life! I come from a family of Tennessee farmers, where the weather, again, is never far from our minds, having the power to make or break each year's crop. My mother, having been fascinated by crop dusters when she was growing up, became a pilot about the time I started



kindergarten. I'm now a private pilot too, as well as an avid gardener; both pursuits are rooted in my farming background and demand close attention to the weather.

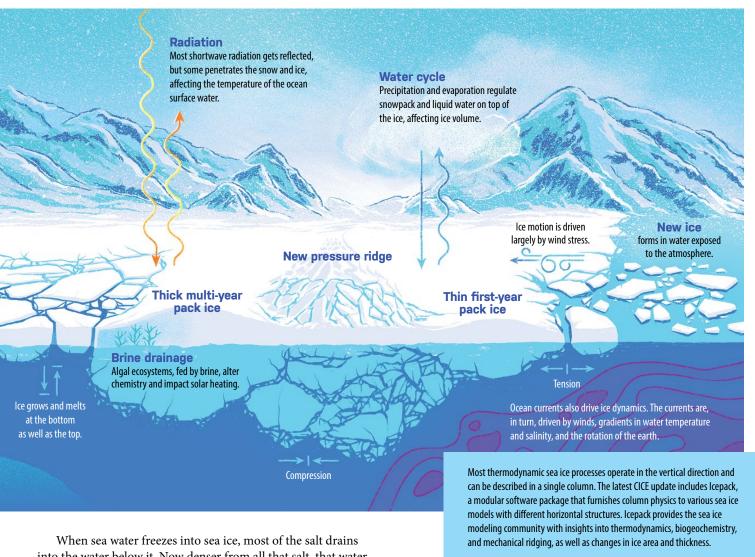
CICE for sea ice

About nine million square miles of sea ice float on top of the world's high-latitude seas and oceans. Sea ice helps keep polar regions cool. It is constantly in motion and constantly changing internally. It influences Earth's climate, wildlife, and people who must contend with it year-round. Sea ice makes navigation difficult, creating challenges for commercial shipping, mining and energy development, fishing, hunting, tourism, scientific research, military bases, and defense operations.

ice reflects much more solar radiation than dark, open seawater, which absorbs it.

Arctic communities, whether indigenous or commercial—and whether human or walrus, for that matter—care a great deal about where the sea ice is. But the most important thing to understand in order to model the physical system is where the ice is not. The open water between ice floes largely controls fluxes of energy, moisture, and momentum between the atmosphere and ocean, and the snow and ponds on top of the ice are crucial for sea ice evolution.

I am the principal developer of CICE, the Los Alamos sea ice model, which models the sea ice environment. CICE incorporates physical effects of the atmosphere and ocean on



When sea water freezes into sea ice, most of the salt drains into the water below it. Now denser from all that salt, that water sinks deeper into the ocean, and migrates toward the equator while warmer equatorial waters circulate into the polar regions. Under the influence of wind and ocean currents, the relatively fresh ice moves to other locations on the ocean surface, and as it melts it suppresses convection and vertical motion in the ocean with a lightweight layer of fresher meltwater. In this way, changes in the evolution of sea ice can modify the global "conveyor belt" of heat moving through the world's oceans. Another way that sea ice alters the earth's heat is through its reflectivity—pure white

the ice, and allows physical feedback mechanisms between them and the sea ice to function in Earth system models. I now lead the CICE Consortium, an international group of institutions jointly developing and maintaining CICE in the public domain for research and operational communities. Originally, CICE was pronounced "sea ice" (it is not an acronym), but although that pronunciation was both fun and appropriate, it created confusion in conversation—do you mean actual sea ice, or the model, CICE?



So the Consortium decided to clear things up and amend the pronunciation to "Sice." Less fun, but more clear.

When I came to Los Alamos in 1994 as a postdoc, my first task on the ocean modeling team was to rewrite a 1970s-era sea ice thermodynamics model to run on supercomputers. When the team began working on the ice dynamics, we encountered

time scales, including the U.S. Navy and the U.K. Met Office. Numerical weather-prediction products from the U.S. National Centers for Environmental Prediction use the dynamics component of CICE. Numerous institutions, including the U.K. Met Office and NCAR, use the CICE model for long-term climate simulations.

Changes in sea ice melting and freezing can alter the global "conveyor belt" of heat.

a numerical challenge: the standard mathematical equations for sea ice stress "blow up," or become mathematically infinite, in a perfectly physical situation, when the ice is not moving. My colleague and mentor, John Dukowicz, solved two problems at once by introducing a clever numerical remedy, which prevented the stress equations from blowing up and also allowed the numerical algorithm to parallelize beautifully. That work became the core of CICE.

CICE 1.0 was rolled out in 1998, and our first community users were the Naval Postgraduate School and, soon thereafter, the National Center for Atmospheric Research (NCAR). Since then, numerous entities around the world have joined the CICE community, both using and contributing to the model. Several institutions use the model for operational forecasting on short

CICE was originally developed for global climate studies using highly parallel computing systems, and it's now also used for smaller scale, higher resolution studies of regional climate processes.

The model solves a collection of mathematical equations that represent the physical processes that occur during sea ice evolution: growth, melting, and movement, along with snow and liquid water carried along with the ice.

In 2018, CICE 6.0 was released with two major new capabilities. First, as numerical approaches for solving the sea ice model equations have diversified across various modeling institutions, separating the sea ice column physics from the main CICE model became desirable. From the original CICE code we created an independent software package, Icepack, which specifically models the column physics, or those phenomena that can be described in a single vertical column. Icepack encompasses most sea ice physics, including biogeochemistry, radiation physics, hydrology, thermodynamics, and mechanical deformation that

results in ridges within the pack ice. Icepack opens fresh opportunities for using CICE's extensive sea ice physical parameterizations in other sea ice models and for single-column applications. Second, our Canadian colleagues contributed the ability to model landfast ice in CICE. This is sea ice that is attached to coastlines or the sea floor and directly affects the length of shipping, hunting, and fishing seasons. Landfast ice can block river channels too, causing floods during spring runoff.

CICE was a part of the initial version of the Department of Energy's new flagship Energy Exascale Earth System Modeling effort, called E3SM. This is a comprehensive Earth system modeling and simulation project to investigate the most critical, energy-relevant scientific questions. The latest version of E3SM uses a new sea ice model called MPAS-seaice, which was developed by the Los Alamos sea ice modeling team. The new model includes CICE's Icepack software for the sea ice column physics and applies advanced new technologies for

CICE continues to be used by many modeling centers, and collaboration is at the heart of its success. CICE is continually being improved, updated, and otherwise modified via dynamic collaborations within the broader sea ice modeling community. My role now is largely to coordinate these efforts, and my hope is that together we will enable an even better understanding of how sea ice keeps the polar regions cool and helps modulate the global climate.

Beyond the sea

other aspects.

I've traveled, literally from one end of the earth to the other, and I still go to the field when the opportunity arises, but truthfully my research has always been done mostly on computers. As the lead developer of CICE, I am ultimately responsible for model development, incorporation of new parameterizations, model testing and validation, computational performance, documentation, and consultation with external model users on all aspects of sea ice modeling, including interfacing with global climate and Earth systems models. Thankfully, I've had a lot of help.

I feel fortunate to have quickly found my niche doing Earth system modeling at the Laboratory. But this was not pure luck—I have had the support of many mentors and peers at all stages of my technical career. I subscribe to the belief that everyone should always have, and always be, a mentor. My mother was my first mentor. She became a private pilot when I was little, supported me in my diverse interests, and modeled courage and integrity every day. When we lived in Alaska, she sewed matching parkas for us, and I still have hers. I also had excellent mentors throughout high school, college, and graduate school—both men and women. It was hard to overcome the intimidation of being the only girl in physics class, to eventually become a self-confident woman in a traditionally male-dominated scientific field. My first trip to a polar region was to Antarctica, to take samples and measurements of real sea ice, with one of the field's most eminent scientists, Steve Ackley. The experience provided a critical boost for me as a young scientist, requiring courage and generating confidence in my own expertise.

The most rewarding aspect of my work at Los Alamos has not been my research, per se, but the fostering of collaboration among other scientists, including students, postdocs, and experts from disciplines outside of high-latitude climate. I'm at least 50 percent manager now, and I'm happy to have spent much of my career making connections among people, which has enabled a lot of great science. I'm now a senior scientist and deputy group leader of the T-3 Fluid Dynamics and Solid Mechanics Group at Los Alamos and a Program Manager for the Laboratory's Biological and Environmental Research programs within the

Collaboration within the sea ice modeling community lies at the heart of CICE's success.

Department of Energy's Office of Science. I represented the United States as a member of the International Arctic Science Committee for the past eight years and was a contributing author for the Intergovernmental Panel on Climate Change Fourth and Fifth Assessment Reports. Recently, I was honored as a Rothschild Fellow of the Isaac Newton Institute for Mathematical Science at the University of Cambridge, U.K., a true honor for a vicarious mathematician.

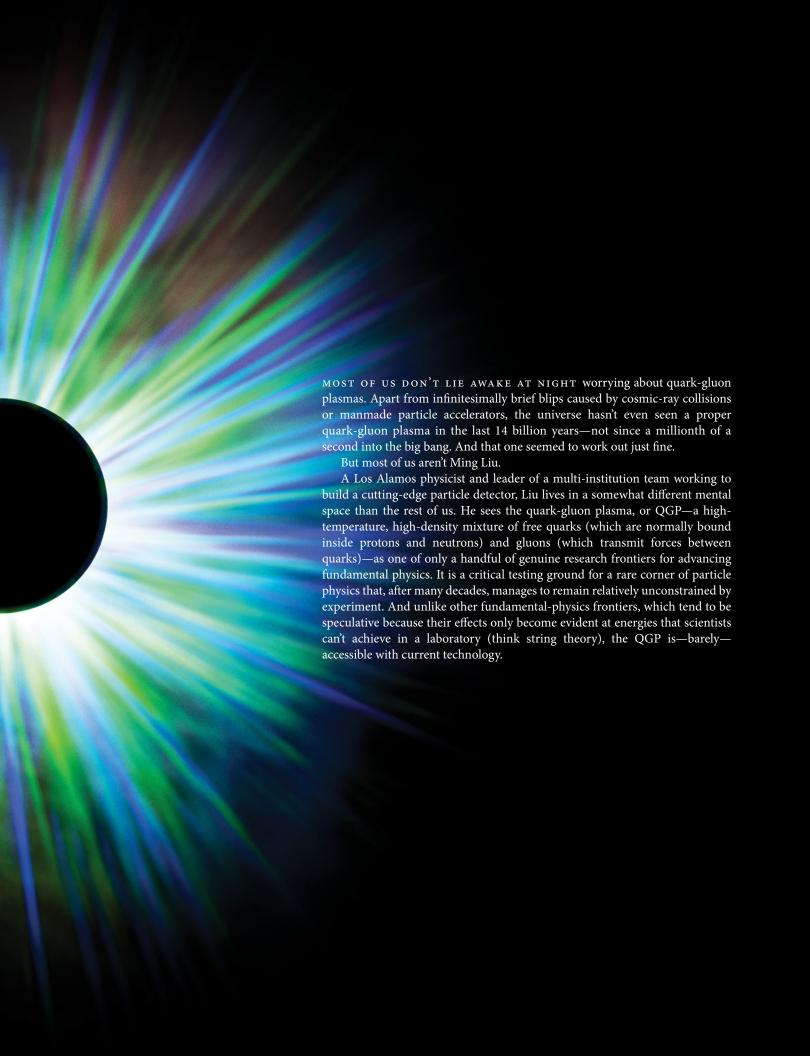
I am a strong proponent of diversity in the workplace. My mentor at Bell Laboratories, Dr. Julia Phillips (now retired from Sandia National Laboratories), had a tremendous influence on my life. Now I encourage girls to consider technical careers when I run STEM workshops. As deputy group leader, I initiated an outreach program in which staff members provide hands-on workshops in Northern New Mexican elementary school classrooms. As a member of the international female pilot organization The Ninety-Nines, I volunteer to take interested girls up in my Piper Cherokee, so they can experience the thrill and empowerment of flying.

As a global community we have to look to the future, mitigate some symptoms and otherwise adapt to the impact of a changing climate. In order to do that, we will have to understand what is happening and why. My work in sea ice modeling is a small contribution to this worldwide, vital effort. I feel a deep sense of sorrow for the state of the earth we are handing to future generations, and yet I feel enormous hope and confidence in them to find beautiful and creative solutions. I encourage young people not just to choose technical careers, but to choose fulfilling and self-sustaining careers, whether they are in STEM fields or not. We can't all be scientists, engineers, and pilots. The world needs musicians too. LDRD

-Elizabeth Hunke

THING of BEAUTY

Los Alamos scientists are building an instrument to probe a key frontier in nuclear and particle physics: subatomic jets of particles produced by the decay of beauty quarks.



Recently, physicists at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC) conducted a landmark study of the production of a particular quark, the charm quark, from within a QGP. The results were decidedly in conflict with many theoretical predictions. The charm quark's large mass should have resulted in a distinctive type of motion within the QGP, but it didn't.

Liu wonders—(is he just examining the possibilities? or perhaps grasping at straws?)—could it be that the charm quark just isn't massive enough to justify the simplifying assumptions that made the theoretical predictions calculable? The only heavier quark that could be used in its place is the bottom quark, sometimes called beauty quark or b-quark. Liu's new detector will excel at capturing evidence of beauty quarks. But will it resolve the conflict? Liu is visibly uneasy about this question.

"I'm afraid," says Liu. "I'm afraid that if this measurement goes the same way, we will have to revisit the entire picture of quark-gluon plasmas. And I don't know how we're going to do that."

Golden opportunity

On New York's Long Island lies Brookhaven National Laboratory (BNL) and RHIC, Brookhaven's signature particle accelerator. A ring-shaped particle accelerator, RHIC does what its name avers: collides heavy ions, such as the gold nuclei used in the quark-decay experiments Liu pursues, at nearly light speed. In 2005, it produced the world's first manmade QGP. Since then, only the LHC near Geneva, Switzerland, has done the same.

Simulated spray of particles produced by the head-on collision of two gold ions traveling at nearly the speed of light. In this simulation of the sPHENIX detector at the Relativistic Heavy Ion Collider, the outbound streaks at the center represent particle paths reconstructed by tracking detectors. (The image on the previous page is an artistic rendering of similar particle-collider output tracks.) Red, yellow, and magenta extrusions show measurements by various sPHENIX calorimeters.

CREDIT: Brookhaven National Laboratory

Key among RHIC's instruments that measure properties of the QGP is the Pioneering High-energy Nuclear Interaction Experiment, or PHENIX. Calling PHENIX an "instrument," however, rather undersells it; it contains a dozen detector subsystems and weighs more than 4000 tons. At one time, it engaged about 600 scientists from around the world, including Los Alamos.

In 2015, the Department of Energy decided to invest in a grand upgrade from PHENIX to super PHENIX, or sPHENIX. It is being designed and constructed by a collaboration of 77 institutions in order to probe a number of important phenomena at the forefront of experimental high-energy nuclear physics. In particular, sPHENIX will investigate jets of particles produced by the decay of free quarks; Liu and his team of staff, postdoctoral scientists, and engineers at Los Alamos are designing and building the innermost sPHENIX component that will most directly observe quark jets and, in particular, beauty-quark jets.

That component, by virtue of its more than 200 million tiny pixels, its exceptional time resolution, and its rapid memory-buffering capacity—all of which are tremendous leaps compared with PHENIX and other current technology—will, for the first time, allow researchers to see every one of the hundreds of particles in one of these beauty-containing jets. By gleaning information from all the jets' outgoing particles, sPHENIX will allow researchers to determine what is happening inside the QGP, similar to the way a medical scan uses various emissions to reveal what's happening inside the patient's body.

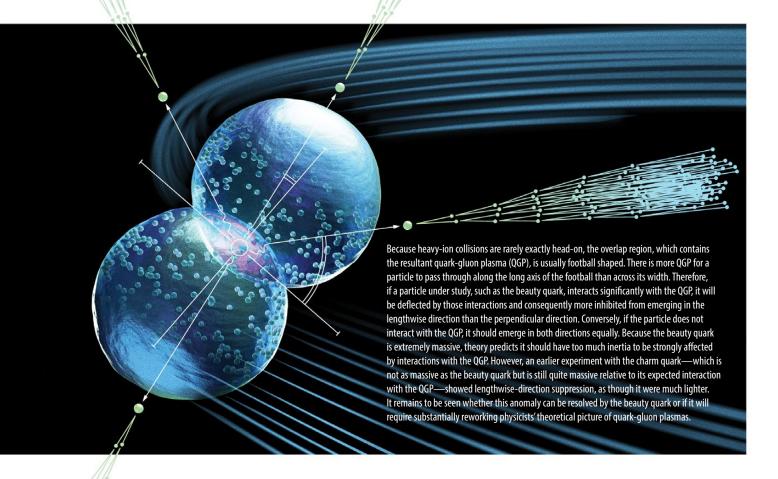
Natural flavors and colors

Much of this extravagant endeavor, like those at other accelerator facilities, is made necessary by the sheer complexity of physics at the quark level. Quarks participate in the strong nuclear force; this is the force that holds atomic nuclei together, even though nuclei are composed of only protons and neutrons. The strong force acts as a very powerful "glue" (hence the "gluons" in a QGP) that binds nuclei together despite the positive-positive electrical repulsion among the protons. But if it seems simple enough to imagine a binding force overcoming a repulsive force, the air of simplicity ends there.

While the electrical force is based on a single quantity, electrical charge, the strong force has not one but three kinds of charge, called "colors," that apply to six "flavors" of quark. Despite the everyday terminology, these colors or flavors are not things that can be understood in terms of human senses. The colors, though labeled in familiar fashion as red, green, and blue, and loosely analogous to the primary colors of light, do not in any visual sense appear red, green, or blue. The flavors—far from garlic, lemon, or chocolate—are organized into three families: "up" and "down" (the quarks from which protons and neutrons are made), "strange" and "charm," and "beauty" and "truth" (or, less poetically, "bottom" and "top"). While the antimatter partner of a proton, say, is just a negatively charged proton, the antimatter partner of a positively charged blue charm quark is a negatively charged antiblue anticharm quark.

Furthermore, while the strength of the electrical force naturally dwindles as two charged particles are moved away from each other, the strong force actually does the reverse. The energy needed to separate quarks grows as they get farther apart, until the energy is so great as to conjure more quarks into existence, right next to the original ones. (This is possible because of the matter-energy equivalence, $E=mc^2$.) In this way, the strong force generally prohibits free quarks from existing. They instead join with other quarks to make particles called hadrons (protons and neutrons are examples) because it takes an impossible amount of energy to separate the quarks. Any energy spent trying to separate

atom, for instance, because hydrogen only has one electron. With the strong force, however, an attempt to probe one quark's properties will always be suppressed by charge and color screening, since extra quarks will simply appear if they weren't there already.



them fails either by being too little to accomplish the task or too much to prevent additional quarks from appearing and getting in the way.

The newly created quarks and antiquarks also thwart any effort to examine the properties of any quark a scientist might

Lost in the crowd

There are basically two things a determined physicist can do about a quark's resistance to being studied, and the sPHENIX collaboration aims

The quark-gluon plasma is a virtually perfect liquid— essentially a new phase of matter.

try to isolate. If the original quark were green, for example, the crowd of newly created quarks surrounding it would possess a mix of colors that includes a slight excess of anti-green to obscure its greenness. Something similar is true for the electrical force; the outermost electrons on an atom don't feel the full positive charge of the nucleus because of other electrons lying in between. But this charge-screening effect only happens if there are other electrons in the way. It doesn't happen at all with a hydrogen

to do both. The first is to seek indirect information, which sPHENIX will do by observing what happens to the beauty and antibeauty quarks created in the heavy-ion collision. Because the quarks resist being separated, they will tend to pair off into a beauty-antibeauty composite state called an upsilon particle. If that doesn't happen,

however, the individual beauty and antibeauty quarks will decay separately, producing distinctive particle jets with beauty-containing hadrons. By tallying the number of upsilon particles that

With this experiment, particle physics will get its report card.

emerge from the collision and comparing with the number of beauty-hadron jets, scientists can infer the properties of the QGP. In particular, the hotter and denser the QGP, the more the quarks will be able to reorganize themselves to obscure one another; this screening prevents beauty and antibeauty quarks from "noticing" one another and reduces the relative number of upsilon detections in favor of beauty-hadron jets.

The other thing sPHENIX researchers can do in the face of quarks' patent shyness is just to accept that they will blend into the crowd and study the properties of the crowd instead. Because while attempting to separate quarks instigates an increasing resistance, the converse is also true: as quarks are crammed in very close to one another, the strong binding force drops away, and each quark moves around more freely. It takes an immense amount of energy to accomplish all this

cramming; RHIC collides ions together at such high speed that the collision generates a temperature of 4 *trillion* degrees Celsius. (By comparison, the center of the sun is downright frigid at only about 15 *million* degrees.) But this is the essence of a QGP: a crowd of quarks so hot and dense that, paradoxically, the quarks can be expected to move about freely.

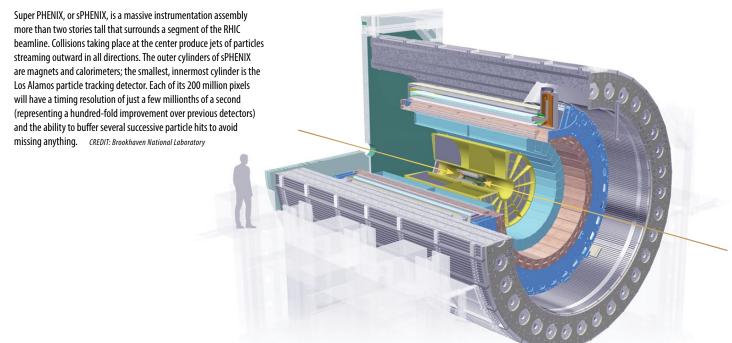
What is quark motion inside a QGP actually like? Physicists once imagined that it would be like the uncoordinated motion of air molecules, with individual particle trajectories divorced from the overall motion of the gas. However, PHENIX and the other three experiments at RHIC showed that this was untrue: the QGP was more like a liquid, with collective motion among quarks in response to pressure variations. Yet unlike everyday liquids, the QGP shows exceptionally rapid thermalization (energy sharing among particles) and almost zero viscosity (frictional resistance to flow), making it a virtually perfect liquid—essentially a new phase of matter.

PHENIX was designed to observe the QGP as the gas of freely moving quarks it was expected to be. The sPHENIX upgrade, capitalizing on new observables like beauty-containing jets and upsilon particles, will be better suited to study the QGP as the liquid-like substance it actually is.

New York jets

Like the gold ions at the Long Island accelerator lab, Ming Liu is on a collision course: a collision course with a fateful b-quark experiment using sPHENIX.

The experiment hinges on a facet of the collision geometry: The ions rarely slam into one another dead-on; sometimes they graze each other. On average, the collision overlap region is shaped like a football, like the middle part of a Venn diagram. Because the football is longer in one dimension than the others, a high-energy b-quark moving through it lengthwise will pass through more QGP than one moving across its width. If the quark is buffeted about by interactions with the QGP, then its trajectory will be somewhat deflected, with b-quarks moving in the long direction affected more than the others. The additional scatter in



the long direction can be quantified by keeping statistics on the outcomes of collisions. However, this length-width asymmetry would only be expected if the b-quark interacts strongly with the QGP. If the b-quark instead moves independently of the QGP and is not deflected by it, then jet production in the two directions should be equal.

One calculates the degree of interaction between the b-quark and QGP, and therefore the expected distribution of b-quark jet directions, by using quantum chromodynamics (QCD, with "chromodynamics" meaning "color dynamics"), the physical theory governing the strong nuclear force. The trouble is, even relatively simple aspects of QCD are mathematically intractable: the equations are far too complicated to solve analytically. So physicists invent perturbative approximations: they imagine a simpler, solvable system and then introduce a small perturbation intended to represent the situation at hand. Liu is working closely with several world-leading QCD theorists at Los Alamos to explore this physics. But the perturbative approximation only

other quarks than a lighter quark can. It should be less strongly coupled to the surrounding QGP. But there would still be the question of why the charm quark wasn't itself decoupled. And that unexpected observation already compounds the earlier one that a QGP is more like a liquid than a gas. Taken together, one might conclude that there are already indications of new physics that differs from what is currently understood.

"I know I'm supposed to be rooting for a surprise," says Liu. "I'm supposed to say, 'I hope the beauty quark confirms the unexpected behavior of the charm quark because that will mean there's something brand new going on—a real discovery.' And part of me does feel that way. But it's daunting. It's hard to see what we're going to do if our perturbative methods go out the window."

In the high-temperature, high-density first microsecond of the big bang, everything that existed was one big QGP. Then the expansion of the universe cooled things down to the point where quarks could no longer be free and instead got bound up inside protons and neutrons. That transition between QGP and normal

It's hard to see what else we can do if our perturbative methods go out the window.

works if the situation at hand really is no more than a small perturbation on an otherwise solvable problem.

Liu's experiment is intended to be just that. The mass of the b-quark is much larger than that of the lighter quarks (up, down, and strange). Its equivalent mass-energy (mc2) is also much greater than the average energy of these lighter quarks in the QGP; that is, even the kinetic energy of zipping around in a 4-trillion-degree froth pales by comparison to the mass-energy of the b-quark. Taken together, these two facts mean that the b-quark should not interact much with the QGP. It would be like a great white shark being knocked around by plankton. That's the reasoning that justifies the small-perturbation approximation: a very slight interaction between the b-quark and the otherwise plain-vanilla QGP.

The beauty of experimental physics

Will the perturbative approximation prove valid? Will the heavy quark be effectively decoupled from the sea of lighter quarks in the QGP? If so, the football-direction experiment should result in directional equality. Liu thinks it will. Hopes it will.

Worries it won't.

"We tried a variation on this experiment with the charm quark already," Liu says. "Its mass-energy is almost ten times greater than the QGP energy. But it acted just like a light quark. It remained strongly coupled to the QGP."

The beauty quark's mass-energy is greater than the average QGP particle energy by a factor of about 40, compared to the charm quark's factor of ten. Will the extra factor of four make the difference? Will it push the experiment into a zone where perturbative QCD is valid, even though it was evidently far from valid in the previous experiment? It might. The b-quark, by virtue of its greater mass, can experience a greater separation from

matter was effectively the origin of the material world. So when it comes to whether or not humanity really understands the QGP, the stakes are high.

"Therein lies both the stress and the joy of experimental physics," says Liu. "One way or another, we are going to get our answer. We are going to find out if we're wrong about all of it quark matter, perturbative QCD, and the early universe too."

Liu's fateful view may be a healthy one. There's something to be said for those times when the stakes are high. Victory is sweetest when there's a real possibility of defeat, and very little is as instructive as defeat. So which outcome will it be?

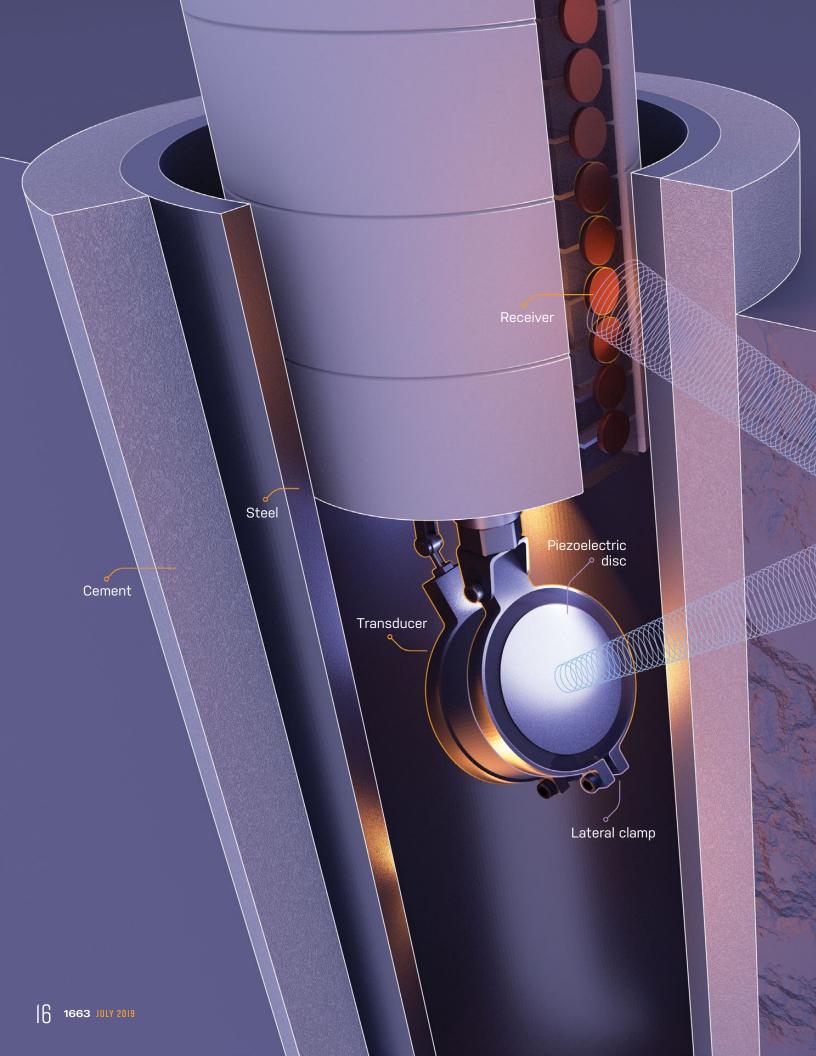
The beauty-quark calculations will be honed. The sPHENIX instrument package will be completed and installed. And particle physics will get its report card. LDRD

—Craig Tyler

MORE PARTICLE PHYSICS AT LOS ALAMOS

http://www.lanl.gov/discover/publications/1663/archive.php

- The neutron lifetime mystery "The Lives and Times of Neutrons" | July 2016
- Matter over antimatter "How We Survived the Big Bang" | May 2015
- Neutrino physics "Neutrino Hunting" | August 2018 "Renegade Particles" | December 2016 "Observing Newtrinos" | January 2012





Underground Ultrasound

A new collimated sound source helps scientists see what can't be seen.

Using sound waves to create images is an idea that's been around for nearly 80 years. Sound waves with a frequency higher than our ears can hear are called ultrasound, and, when bounced off of some obscured object, can relay information about the structure of that object.

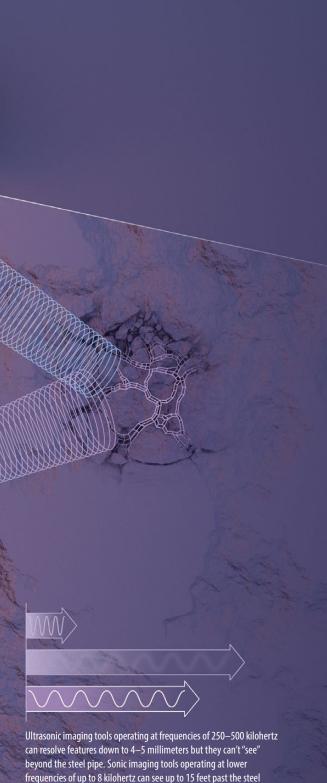
The Department of Energy has funded a program called SubTER (Subsurface Technology and Engineering R&D), which facilitates collaborative research to address subsurface technical challenges. One such challenge is the reliable imaging of underground structures like oil wells. Simplistically, an oil well is a vertical steel pipe encased in cement and embedded in natural rock. Under the extreme pressure and heat involved in oil retrieval, a crack or deformation in any of these structures could cause the structure to fail catastrophically, so it's important to monitor the wellbore's integrity. Ultrasonic imagers use high-frequency sound waves to produce high-resolution images, but the waves cannot penetrate beyond the steel pipe, so the cement and rock strata can't be monitored. In contrast, imagers operating at lower frequencies that can reach these outer layers produce only low-resolution images containing limited information.

As part of a SubTER multi-lab collaboration, Cristian Pantea, an acoustics physicist at Los Alamos, along with ultrasound scientist Vamshi Chillara and retired Lab Fellow Dipen Sinha, has invented a new kind of ultrasonic transducer, which, together with a receiver, makes up a new imaging tool. Called ACCObeam (acoustic collimated beam), it is the best of both worlds, having the penetration power of lower-frequency probes and producing high-quality images like higher-frequency probes.

Ultrasound imaging transducers use piezoelectric materials to convert electricity into sound waves. But the sound waves these materials produce spread out considerably; they aren't collimated. Collimation is the removal of nonparallel wave propagation so that the resultant beam spreads out minimally as it travels (a laser pointer is an example of collimated light). Early on, the ACCObeam team was looking for ways to reduce the nonparallel sound signals because they detract from and compete with the main signal. Through extensive experimentation and theoretical simulation, the scientists discovered that by laterally clamping their piezoelectric disc (as shown), they could collimate their sound waves. The clamp solved another, more practical problem too: how to physically attach the transducer to the end of the probe.

Since that breakthrough, Pantea, Chillara, and Sinha have continued to experiment, theorize, and simulate, developing a detailed understanding of the physics behind sound collimation so they can fine-tune and control their ultrasound signals. ACCObeam is powerful and inexpensive compared to other options available. It's also much faster, imaging in less than a day what used to take a week. Pantea, Chillara, and Sinha are still perfecting the design, but they are already thinking about other ways this technology can be used. Bomb detection, long-range undersea communication, medical imaging, and the wireless powering of implanted medical devices are a few places where they can see ACCObeam shining.

—Eleanor Hutterer

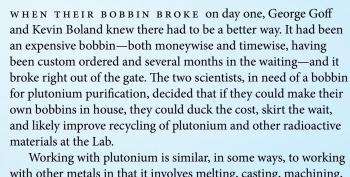


pipe but can only resolve features down to about one foot. ACCObeam circumvents this ostensible tradeoff, allowing ultrasound to penetrate

the rock and produce high-quality, information-rich images.

RESOURCE REVOLUTIONS

3D PRINTING HELPS CONSERVE RESOURCES
AND REDUCE WASTE IN SERVICE OF THE
LABORATORY'S PIT-PRODUCTION GOAL



Working with plutonium is similar, in some ways, to working with other metals in that it involves melting, casting, machining, and welding. But plutonium is quite different from most metals—it undergoes radioactive decay, has unexpectedly weak magnetism, expands and contracts more than other metals, and increases in density, rather than decreasing, when it melts. These traits make plutonium metallurgy particularly complicated and difficult. To keep the workers safe and the material secure, plutonium facilities are extraordinarily specialized and astonishingly expensive to build.

Los Alamos is the National Nuclear Security Administration's Center of **Excellence for Plutonium Research** and Development. As such, it is one of the national laboratories that has been charged with scaling up the production of pits—the plutonium cores used in nuclear weapons—to 80 per year by 2030, in support of the nation's strategic nuclear deterrent. In order to meet this mission goal, Laboratory scientists are looking for creative new ways to reduce, reuse, and recycle within the pit-production process. Costs can be cut by reducing the footprint of these chemical processes within the facility, by reusing as much plutonium as possible, and by recycling key materials to minimize waste and maybe generate a bit of revenue to offset costs.

But first, back to the busted bobbin.

A commercially produced, conventionally manufactured bobbin is made by winding narrow plastic tubing around a central steel spool (left). A house-made 3D-printed bobbin is essentially one piece of transparent material into which a continuous coiled channel has been built. PHOTO CREDIT: Michael Pierce



Reduce

The bobbin that broke was roughly the size and shape of a coffee can and consisted of dozens of meters of narrow plastic tubing coiled around a central spool. The bobbin is the business end of a machine called the coil planet centrifuge, which uses centrifugal force for chromatography—the physical separation of particles in a suspension through which different particles travel at different speeds.

The coil planet centrifuge does high-speed counter-current chromatography (HSCCC) and was originally developed to separate different kinds of blood cells (e.g., lymphocytes, granulocytes, erythrocytes) in a blood sample. The technique is called "counter-current" because of how two immiscible liquids interact within the bobbin as it spins. The two liquids, an organic phase like oil and an aqueous phase like water, occupy the bobbin's plastic tubing as the bobbin spins around. One of the liquids is held in place (not flowing into or out of the bobbin) by centrifugal forces, while

the second phase flows through the bobbin, moving past the immobile phase within the plastic tubing. where radioactive materials are handled—it could free thousands of square feet of invaluable facility space for other types of processing. But there were a lot of problems adapting the commercial unit to work inside a glovebox, not least among which was the bobbin. Made mostly of steel, the centrifuge pieces are heavy to lift and clumsy to maneuver within the glovebox, and they are easily damaged by some of the chemicals used in plutonium processing. The opacity of the system was also problematic.

Marchi explains, "We want to understand the hydrodynamics and chemistry of separation within the commercial unit, but it is literally a black box—all the moving parts are encased in a steel housing. I want to be able to see what's happening."

COSTS CAN BE CUT BY REDUCING THE FOOTPRINT OF CERTAIN CHEMICAL PROCESSES WITHIN PLUTONIUM FACILITIES

Due to the high rotational speeds, the result of this countercurrent chromatography is the fast and efficient transfer of molecules from one phase to the other.

HSCCC is used for all manner of separations, ranging from herbal medicine preparation to weapons-grade plutonium purification. Goff and Boland were pursuing the latter of these as part of a larger plutonium-separation project led by Laboratory engineers Steve Yarbro and Brad Skidmore. The team decided they needed a 3D-printing expert, so they brought in chemical engineer Alex Marchi to help with the bobbin problem.

Initially, the scientists bought a commercial coil planet centrifuge to study HSCCC as a reduced-footprint method for purifying plutonium. If the machine could be accommodated inside a glovebox—a fully sealed glass and steel workstation

Marchi and Goff explored 3D printing as a way to build a better bobbin. A form of additive manufacturing, 3D printing deposits layer upon layer of material—usually some sort of plastic or resin—until a single, solid object has been formed. The technology is particularly useful for making items with intricate internal spaces and proved ideal for bobbin building.

The in-house 3D-printed bobbins Marchi and Goff designed can be manufactured in just four days, compared to six months for the commercial ones. They also cost about 85 percent less.

And these bobbins are indeed better—they are optically transparent, very lightweight, and resistant to strong acids, organic solvents, and radiation damage. And because each is one solid piece there are fewer points of failure. In fact, the only failures the team has seen so far have been post-production machining mishaps. But because of the short manufacturing timeline and comfortable cost, when over-eager threading and tapping of the ports causes a bobbin to crack, it's easy enough to make a new one.

As the team worked with the commercial centrifuge in pursuit of the best bobbin designs, Goff and Marchi realized 3D printing could improve more than just the bobbin. Conventional machining imposes certain constraints on design; what gets built is whichever design is most practical from a manufacturing

bobbins, spindles, clips, clamps, gears, and manifolds, improving functionality and cutting cost at every turn.

Reuse

Plutonium is a manmade material that is produced by bombarding uranium with neutrons. Throughout the Cold War, plutonium recycling was driven by the cost of production—it was cheaper to recover it from waste than to make more. These days, recycling is still imperative, but it is now driven by the desire to limit the amount of nuclear waste being sent to geologic disposal repositories.

The scaled-up pit-production mission at Los Alamos, or plutonium sustainment, means that maximum plutonium recovery is more important than ever. There are multiple types of material from which recovery is necessary: each step of making a pit—casting, machining, and welding—produces waste in the form of residues, filings, and slag. These get dissolved into an acid solution, which is then processed chemically to recover usable plutonium.

Traditionally, aqueous recovery of plutonium entails multiple separation and purification steps that produce a large volume

of hazardous, radioactive liquid material. Not only would HSCCC reduce the facility footprint of these processes, it would improve recovery and reduce waste as well.

HSCCC uses the hydrodynamic behavior of two immiscible liquids to efficiently extract small quantities of sample from a large volume of liquid. The bobbins of the centrifuge travel in two ways: they rotate around their own central axes at around 1600 rpm, and while they're doing that, they also revolve opposite one another like planets around a shaft in the center of the centrifuge. The combined force, around 200 times the force of gravity, allows the coil channel of the bobbin to retain the stationary phase (not unlike the amusement park ride called the Gravitron), while the mobile phase gets forced through with a pump. The rapid motion causes the two phases to mix quickly and thoroughly within the channel, maximizing the rate of molecular exchange between the two phases. The result is highly efficient mass transfer: the small amount of plutonium that was in the mobile phase winds up in the stationary phase, while the mobile phase moves out the other end, taking contaminants with it.

The recovered and purified plutonium gets reused. But what happens to the contaminants?

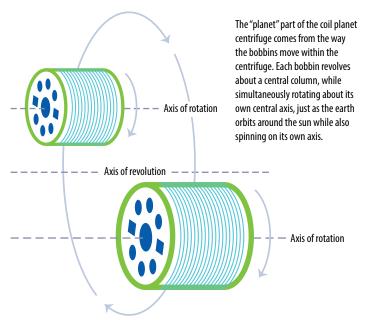
Recycle

About 80 percent of the recoverable plutonium is contained in 20 percent of the pit-production waste products. If these products, mainly chloride salt residues, were all sent to waste repositories, they would amount to many drums and dollars worth of unnecessary waste. So, recovery is a cost-saving twofer: it rescues reusable plutonium and eliminates the lion's share of the radioactivity in the waste.

Another radioactive manmade element driving the disposaldrum count is americium. Americium is the main contaminant that accumulates in weapons-grade plutonium as it ages. When plutonium is produced in a nuclear reactor, some of the product takes the form of plutonium-241, which naturally

ABOUT 80 PERCENT OF THE RECOVERABLE MATERIAL IS CONTAINED IN 20 PERCENT OF THE WASTE PRODUCTS

perspective, not necessarily the design that will do the best job. For example, a 90-degree bend is not ideal for fluid flow, but using more gradual bends means using more parts, which drives up the cost of manufacturing. With 3D printing that is no longer true, so Marchi got creative, incorporating smoother curves in her design, which reduced flow disruption and enabled higher-efficiency separation at no added cost. Marchi has redesigned every single part and is now printing



decays into americium-241 through the release of a beta particle (a high-energy electron). Naturally, the older the plutonium is, the more americium has accumulated, so for plutonium sustainment the americium has to be removed, and HSCCC is a fast and effective way of separating the two. In the past, separated americium was indeed relegated to waste repositories, but several new technologies can make good use of it, so it now gets recycled at the Laboratory as a resource in its own right.

When an alpha particle (made of two protons and two neutrons) emitted by a highly radioactive americium nucleus interacts with a beryllium nucleus, the beryllium nucleus releases fast neutrons. It turns out that this combination, americium and beryllium, makes a neutron source that is useful to scientists, farmers, land developers, and, especially, oil and gas prospectors. The americium-beryllium neutron probe is a reliable way to measure the quantity of water in the soil. When fast neutrons from the probe collide with the hydrogen of water molecules in the ground, the neutrons lose much of their energy, returning to the probe as slow neutrons. The proportion of fast neutrons going out to slow neutrons coming back helps estimate the water content of the soil. A similar effect helps energy explorers determine where and how to drill for oil and gas.

Other potential uses of americium as a commodity rather than contaminant include neutron radiography, a nondestructive imaging technique for materials science; radioisotope thermoelectric generators, which provide power to unmanned remote facilities and spacecraft; and, perhaps most palpable, home and hearth protection via domestic smoke detectors. Alpha particles released from a small amount of americium ionize the air inside the detector, causing a flow of ions between two electrically charged plates. Smoke particulates entering the detector absorb the alpha particles and disrupt the flow of ions, which triggers the alarm.

By improving recovery of both plutonium and americium, pit-production waste streams can be trimmed and costs offset.

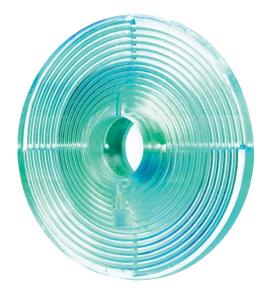
Revenue

This project will significantly reduce the footprint of chemical processing in the Laboratory's plutonium facility. It will improve how plutonium gets reused and help recycle erstwhile contaminants into the marketplace, creating a revenue stream and reducing radioactive waste.

One challenge that Marchi, Yarbro, and Goff are tackling now, which could yield significant returns outside of the Lab's national security purview, is to demonstrate how 3D-printed HSCCC could be useful for other industries.

"Plutonium processing is necessarily a batch process," says Yarbro. "Material control and accountability, as well as criticality safety, will always require it to be done in batches. But continuous processing can be useful for other industries. So, we will develop those designs too."

One notable area where HSCCC shows promise is the recovery of rare-earth elements from fly ash, a byproduct of coal combustion. Rare-earth elements, which are used in all manner of modern tech, including hybrid cars, portable electronics, and those handy little super strong magnets can be, yes, rare, but they can also be expensive. Fly ash is typically placed in landfills or stored indefinitely by powerplants. This seems shortsighted, and scaled-up HSCCC could be a productive solution.



3D-printed bobbins can be made in different shapes and sizes for different applications. Here, the transparent spiral containing the fluid channels was built by stereolithography, which uses ultraviolet light to crosslink liquid polymers into a solid. The spiral design contrasts with the helical design on pages 18-19 by inducing a sharper gradient in the centrifugal forces over a shorter path length as the fluid spirals outward.

PHOTO CREDIT: Michael Pierce

An even more consequential problem that HSCCC might solve is water desalination. As an alternative to reverse osmosis, methods are being developed to chemically extract purified water and leave the salt behind. HSCCC could be used to implement this chemistry and enable a significant reduction in the energy required; so far, the technique appears promising. With scaling and continuous processing—significant challenges for desalination—HSCCC could be useful for agriculture or even the production of drinking water.

The cost-saving opportunities afforded the Laboratory by 3D-printed HSCCC devices are various and sundry. The pit-production process itself would benefit from faster and more efficient plutonium recovery, cheaper and more versatile machines, smaller facility footprints, and fewer drums of waste. From a broader perspective, the recovery of other profitable resources like americium and rare-earth elements can raise revenue streams where previously only waste streams ran.

And it all started with that broken bobbin. LDRD

-Eleanor Hutterer

MORE **PLUTONIUM SCIENCE** AT LOS ALAMOS

http://www.lanl.gov/discover/publications/1663/archive.php

- New technology for nuclear facilities "Intelligent Infrastructure" | February 2019
- **Subcritical plutonium implosion** "The Bomb without the Boom" | October 2017
- Aging of plutonium "In Their Own Words" | December 2016
- Plutonium's missing magnetism "A Community of Electrons" | October 2015





in so doing, create even more projectiles and therefore more collisions. The 2013 movie Gravity (starring Sandra Bullock and George Clooney) portrayed this crisis, known as the Kessler effect after the NASA scientist who first proposed it, as a single runaway event. But in real life, it probably wouldn't happen all at once. Instead, over the years, the rate of satellite destruction and shrapnel production would increase collisions every ten years, every five, every two—until low earth orbit becomes effectively unusable for the better part of a century. And short of the full-blown destruction of everything in low earth orbit, an "economic Kessler effect" could prohibit the investment necessary to

photons of light, which carry about a billionth of the energy of a mosquito in flight. Perhaps, by extension, human vision might directly perceive purely quantum phenomena, such as a superposition in which the photon is in two places at the same time. Tantalizing research from Holmes and others is beginning to suggest that at least the former may be true, even though singlephoton detection as a technology, while well established, remains quite specialized.

"The rod cells of the human eye are single-photon detectors," says Holmes. "It's just a question of whether or not the signal makes it all the way to the conscious mind, rather than getting lost or discarded as noise."

Looking directly at the sun (not recommended) would allow the eye to take in a few thousand trillion photons per second. Yet human eyesight can possibly detect a single photon and can definitely detect a few. And if such extremely low-power optical signals can trigger a human eye that's optimized for signals

TO REGISTER AN INCREDIBLY FAINT SIGNAL

FROM A TINY, SELF-POWERED, MULTIDIRECTIONAL TRANSMITTER: TOO PIE IN THE SKY?

build and launch a satellite because its expected lifetime amidst the orbital debris is too brief.

Currently, the U.S. Air Force conducts extensive satellite tracking and can often arrange for one object to adjust its trajectory to avoid a potential collision. But to enact such a solution requires that both objects have been located and that at least one of them is capable of receiving instructions, equipped with a means of propulsion, and identifiable, so that the satellite's operator can be contacted and instructed to make the course adjustment-hopefully with sufficient lead time. Otherwise, there's no seeing the approaching brake lights, slowing down, or changing lanes. There are no space traffic jams. Only collisions.

Quantum vision

Two years ago, before joining a Los Alamos team working to ease the satellite overcrowding problem, Rebecca Holmes was still in graduate school. There, studying quantum optics and collaborating with a Nobel prizewinner, she researched a hypothesis that is tantamount to heresy in conventional physics circles: that the human visual system might be able to see individual

exceeding trillions of photons per second, then what might be possible with a high-end photon detector optimized for extreme low-light conditions? Just how little energy could be put into a signal say, sent from a satellite to a ground station—so that it can still be seen?

Signal science

From his office in the Laboratory's Nonproliferation and International Security Center, David Palmer pursues a technological solution to the orbitalovercrowding problem: something akin to air-traffic control, but for space traffic. Ideally, every space vehicle, whether currently in use or previously decommissioned—and for that matter every scrap of space junk—would be identifiable, controllable, and in constant communication with a central traffic-control ground station. This is not currently the case. To make it so, every new satellite launched would need to be equipped with some kind of transmission capability allocated to space-traffic control.

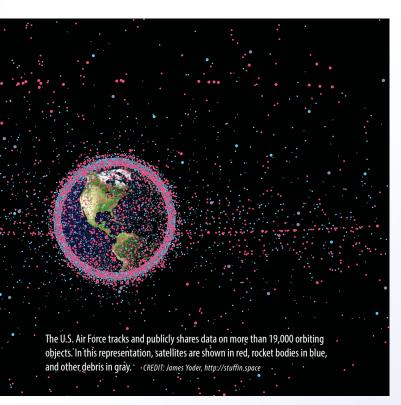


"That's already a sticking point," Palmer says. "Adding to a satellite's mass, power consumption, or functionality—and a radio antenna, for example, adds all three—always means increasing cost. But the cost needs to be negligible so that every government, every space research organization, and every telecom company

will participate, down to the universities, colleges, and even high schools now putting up their own CubeSats." The idea is that, over time, satellites with traffic-control functionality will replace what's up there now. But to catch on, the system would not only need to be cheap, but also tiny, self-sufficient, and completely trouble-free.

For a satellite, that's a tall order. Nominally, it would seem to require adding a dedicated radio antenna or partially repurposing an existing one. A dish-style antenna uses little power for transmitting but must be actively pointed toward the receiver, either by turning the dish or the whole spacecraft. That often means stopping whatever else the satellite is doing and consuming either power or propellant to make the turn. Alternatively, a rod-style antenna broadcasts in all directions and therefore need not be pointed, but it requires significant power because the signal must go out in every direction with enough strength to be picked up clearly in any one of them. Either solution is likely to be too resource-intensive for a traffic-management function that's not directly related to the satellite's intended purpose. What's needed is the best of both worlds: no pointing and no appreciable power consumption.

Palmer's solution is almost too pie in the sky to be believed: an incredibly faint optical broadcast from a tiny, self-powered transmitter that doesn't need to be pointed. Rather, it transmits in an enormous 120-degree cone, wide enough that the beam is likely to hit a ground receiver during a pass overhead, assuming that it's mounted on the Earth-facing side of the satellite.



The signal is composed of tremendously spread-out red laser light that can, nonetheless, be detected by a sensitive enough single-photon detector attached to a telescope, pointed at the satellite. Palmer's colleague David Thompson and his team have developed what turns out to be the perfect detector for this purpose—a phenomenally sensitive single-photon imaging



CubeSats, introduced in 1999, are responsible for much of the rapid proliferation of objects in low earth orbit. As of early 2019, more than a thousand have been launched, exceeding the rate of non-CubeSat launches in recent years. They typically use commercial off-theshelf components, have a mass of up to 1.33 kilograms (2.9 pounds), and occupy a frame 10 centimeters (4 inches) on a side, although this Los Alamos CubeSat, when folded up rather than deployed as shown, is $10 \times 10 \times 15$ cm. PHOTO CREDIT: Michael Pierce

camera. And that camera, or even a lesser system based on singlephoton sensing without full-blown imaging capability, can pick up an ultrafaint, ultralow power optical transmission from a satellite if it is taught what to look for.

In theory, this should work. Still, much remains to be done to bring it from concept to testing to practical reality. So Palmer recruited Holmes, the unconventional single-photon sensing expert, to Los Alamos-and to the cause of rescuing low earth orbit.

Hay in a haystack

What does it feel like to see just a few photons with your eye? "You are rarely sure you saw anything," says Holmes. "In the clearest trials, you might perceive a slight motion or a tiny suggestion of a flash." Confounding such an inherently inconclusive perception, any number of thermal noise processes or even outright hallucinations—could produce a false detection. And with any other light in the room at all, the signal would be completely drowned out.

These difficulties largely mimic the challenge of using an electronic single-photon ground detector to pick up a satellite's ultrafaint optical signal. The transmitter, which the team has dubbed the Extremely Low Resource Optical Identifier, or ELROI, will be roughly the size of a Scrabble tile, including its own dedicated solar cell. It won't "know" when or from where it is being tracked, so it will broadcast essentially continuously across the face of the earth. Matching the solar cell's available power to the power consumed by the transmission sets the signal strength: very, very low.

Even on a dark, moonless night, sunlight reflected by the satellite itself will easily overwhelm ELROI's signal. After putting a very restrictive filter on the detector scope to eliminate 99 percent of the incoming sunlight—all but a narrow range spanning the transmitted wavelength (that is, the exact shade of red)—photons of the correct wavelength in the reflected sunlight will still



The European Space Agency's Envisat performed an Earth-observing mission between 2002 and 2012. when contact was lost. At more than 8 tons, it is the most massive inactive satellite. It orbits at a particularly crowded altitude and regularly passes within a few hundred meters of other known satellites. A collision involving Envisat, even with a small piece of space debris, could dramatically accelerate a chain reaction of collisions in low earth orbit. PHOTO CREDIT: ESA

outnumber signal photons by about 90 to one. And simply detecting an excess is not good enough; the transmission would need to convey unambiguous information on the identity of the satellite, similar to a license plate on a car. To do that, the receiving system would have to somehow figure out which photons are likely to be signal photons and which are not.

This is a classic problem, separating signal from background or noise. For example, how might a researcher determine whether a human test subject really saw a single photon of light? Holmes sometimes envisions returning to this line of investigation at some point, after she has done her part to save the skies. First, she would have to repeat

imply that subjects were seeing single photons, at least sometimes. Only then, from a standpoint of understanding the rate at which single photons are perceived (if they are perceived at all), could she begin to examine the deeper question of whether human beings can perceive attributes of the photons' quantum states.

A satellite-signal receiver would also require the statistical analysis of many, many cycles of the same transmitted data string, from which to derive a basis for identifying certain flashes as containing a signal, not just background light. But unlike the human test subject, the satellite signal receiver would have to read the transmitted data reliably, not just determine whether it was on the left or the right. So it would need some additional way to differentiate signal photons from sunlight and other noise—something more than just statistical repetition.

Microsecond magic

When the first pulsar was discovered—
a pulsing astronomical radio source with a pulse
rate more precise than an atomic clock—its

discoverer reportedly mistook it for a possible sign of alien technology. Pulsars were quickly identified with rapidly spinning neutron stars, which produce a flash with each rotation, like a lighthouse, but nonetheless, their tremendous regularity provides a model for separating the artificial from the natural. A manmade signal delivered with a precise, specific timing can be distinguished from the continuous background blur of sunlight, moonlight, starlight, and other forms of optical noise.

ELROI has been designed to transmit a satellite-identification number in 128 bits of data at a frequency of one kilohertz. That is, it either sends a flash or doesn't—a one or a zero—every thousandth of a second. After 128 thousandths of a second, or 128 milliseconds, the full identification number is complete and begins again, transmitting the full satellite ID almost eight times per second. That's the repetition; that's how the necessary detection statistics are obtained. The ground station will typically track the satellite across the sky for several minutes, so it will

receive the same 128-bit sequence hundreds or even thousands of times in a given orbit.

Each bit, or flash of light, lasts only a millionth of a second, which is a thousandth of a millisecond. So each millisecond begins with a microsecond flash (or not), followed by 999 microseconds of nothing. That makes two critical aspects of ELROI possible. It cuts power consumption by a factor

of a thousand, since it's only transmitting for one microsecond every millisecond. And it creates a very specific timing for the data photons: They arrive only in a specific microsecond at the beginning of every millisecond, like clockwork. The ground receiver can therefore ignore all the photons that arrive during the other 999 microseconds.

DETECT A SINGLE PHOTON AND CAN DEFINITELY DETECT A FEW

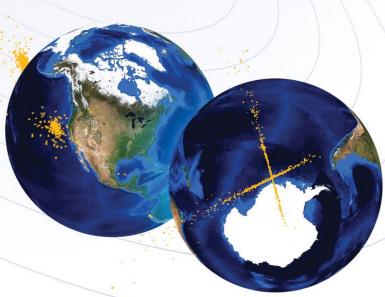
the experiment many, many times, with photons presented randomly on either the left or right side of the eye, to obtain statistics on how often a test subject could choose the correct side. Accuracy above guessing randomly, or 50 percent, would

In practice, isolating the photons that arrive with the proper timing is done with a "fast-folding algorithm" (the same algorithm used in modern pulsar searches) to identify the cyclical pattern. On occasion, some photons of sunlight of the right color will just happen to arrive during the proper microsecond, but they will be few enough that they can be rejected statistically, after many iterations of the complete 128-millisecond transmission. In other words, the extreme faintness of the signal relative to its background, even within the narrow wavelength band used, can be overcome by timing and repetition.

For instance, if the satellite ID were a six-digit number like most automobile license plates, then after filtering by wavelength and applying the fast-folding algorithm, such a transmission might be received several hundred times as "XYZ123," twice as "XYH123," and once as "XYZ193," making it easy to determine

PRECISE TIMING HELPS SEPARATE A FAINT MANMADE SIGNAL FROM ITS NATURAL BACKGROUND

the real ID. In fact, in a two-minute segment of a satellite passing overhead, the ELROI system, using state-of-the-art error-correcting codes, has less than a one-in-a-billion chance of misidentifying a satellite ID. And even if an ID number were to be misread, the mistake would be discovered instantly because the vast majority of 128-bit numbers will not have a satellite assigned to them—unless humanity launches 2128 more satellites.



More than 2000 new pieces of debris were tracked (and, presumably, many more remain untracked) in the wake of a 2009 collision between two satellites: (left) twenty minutes after the collision and (right) 50 minutes after the collision.

CREDIT: Rlandmann/Wikipedia; data based on work of Astronautics Research Group, University of Southampton

A little vision

At Los Alamos, experiments are in the works to observe the faint test beams from orbit with Thompson's single-photon imaging camera. For the test phase especially, the camera's imaging capability is a major bonus, easing the tracking requirements by allowing a satellite to be off-center within the telescope's field of view. However, commercially available singlephoton detectors can also read the satellite ID transmissions without full imaging capability, so the essential technology to use ELROI is available to any government or research organization. Essentially, ELROI's transmission technology is small, lightweight, cheap, self-powered, and otherwise self-sufficient, and its reception technology is available to anyone. For that reason, its creators believe it has what it takes to catch on and dramatically mitigate the space-traffic crisis.

> To actually track an ELROI-tagged satellite and read its ID would still require knowing the orbital details of the satellite in question: where and when to point the telescope. That information is always available to whoever controls the satellite and, in some cases, to an external agency with sufficient tracking capability, such as the Air Force. But even for the Air Force, satellite identification is not guaranteed and can

be absent whenever satellites fail to be registered immediately upon launch or, for example, when they cross paths in a confusing way. ELROI would nullify these problems going forward and, given the rapid over-proliferation of space objects, none too soon.

Still, there is a hint of irony in this manner of solution. There can be no question that developing a practical system capable of saving low earth orbit from becoming a hazardous wasteland is a tremendous multidisciplinary challenge for the modern age. And yet, paradoxically, at its core is single-photon detection the ability to perceive the absolute faintest possible blip of optical light—which, if you can read this, you might be able to do all by yourself. LDRD

—Craig Tyler

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With visions of plenty, Los Alamos is helping farmers in Northern New Mexico use science to improve their strategy against damaging frosts.

"THE APPLE SUPPLY IN NORTHERN NEW MEXICO ISN'T AS RELIABLE AS ONE WOULD LIKE," says Los Alamos electrical engineer Gary Goddard. In his free time, Goddard ferments apple juice with his friend Mike Steinzig, a weapons engineer who has been making hard cider for the past 19 years. Gathering apples from a variety of local sources, they usually make nearly 100 gallons a season, but a plentiful apple harvest at any given farm only happens in about one out of every three years. On the surface, the problem is that late spring frosts kill the apple blossoms. But the real problem is that unseasonably warm days in the middle of winter cause the trees to bloom too early.

Although some people might delight in a 60-degree sunny day in January, farmers (and skiers) do not. Plants need cold weather; it is part of their annual cycle of dormancy, growth, and fruiting. Too many warm days during the winter months might encourage a plant to bud early, and when the frosts return in late spring—as they always do—the buds can freeze and fail to produce fruit. A smaller or nonexistent apple crop might be a mere disappointment for Goddard and Steinzig's cider-making hobby, but for a farmer whose livelihood depends on the harvest, frost damage can be devastating.

"The last five years have been really disheartening—to see all the blossoms and potential fruit and then one night it's gone," says Tim Seaman, who owns the Manzanar Los Silvestres apple orchard in Abiquiu, New Mexico.

In an effort to help farmers facing this annual challenge, Goddard and Steinzig have been leveraging expertise from their day jobs to analyze the frost problem and improve crop protection for Seaman and other growers in Northern New Mexico. Since 2017, the Lab team has been monitoring variables such as temperature, humidity, and wind at each farm and is now beginning to make recommendations. The scientists aim to help farmers mitigate frost damage by making informed decisions—based on each farm's





unique microclimate—about how and when to protect their crops. The goal is to use data to implement the right strategy for each farm and to deploy a low-cost, easy-to-use sensor system to give growers real-time warnings during the critical spring weeks when their crops are most vulnerable.

Fire and ice

Created as a partnership between the State of New Mexico and the national labs, the New Mexico Small Business Assistance program (NMSBA) provides unique technical expertise to small businesses facing complex challenges. Businesses apply for assistance from the NMSBA program (https://www.nmsbaprogram.org), which uses a state tax credit to enable Laboratory participation. In 2017, when two farm owners—Seaman along with Christopher Bassett of Freshies of New Mexico in Lyden—approached the NMSBA with concerns about protecting their crops from frost, the organization requested that Steinzig, Goddard, and their colleagues tackle the problem. The NMSBA funding allows the scientists to examine frostmitigation methods, to study how frost moves across varied terrain, and ultimately to provide individualized data-based recommendations for each farm to improve frost protection.

"The NMSBA was created to promote economic development in rural areas, and agriculture is a big piece of that," says Julia Wise, a project manager for the NMSBA. With this in mind, the organization stepped in to help the farmers, for whom frost protection is a priority in order to ensure consistent, dependable crops each year.

"When the trees are flowering, a 28-degree night could result in a 10 percent loss of fruit," says Bassett. "But just a few degrees colder, say 24 degrees, could make it more like a 90 percent loss." Freshies of New Mexico is Bassett's family business; he and his wife operate two farms in the Española valley in Northern New Mexico. Faced with a daunting frost risk each season, Bassett has put a significant amount of time and money into infrastructure for frost protection. By working with Los Alamos, Bassett hopes to optimize his approach and get the most out of his investments.

At one of Bassett's farms, he uses sprinklers to protect the crops by coating

the plants with a layer of ice on cold nights just before the frost comes. This process works because heat is released as a result of the ice formation; that heat is called the latent heat of solidification. However, this approach only works within a narrow range of temperature and wind conditions, so Bassett has been looking into other strategies. His largest investment has been to build 12 heated greenhouses (each one with a 31 \times 300-foot area) at his second farm where he grows everything from tomatoes and chiles to peaches and apples.

On cold nights, farmer Christopher Bassett of Freshies of New Mexico occasionally sprays water on his apple blossoms to protect them because heat is released as the water turns to ice—the latent heat of solidification. This is one of many strategies farmers use to protect their crops during the springtime when their plants are most vulnerable. PHOTO CREDIT: Taylor Dale Bassett



"Some folks think I'm nuts to try this," says Bassett, referring to the fact that it is unusual to plant an entire orchard of fruit trees inside a greenhouse.

Not everyone, however, has the capital to invest in heated greenhouses or sprinkler systems. For centuries, many farmers have fought frosts using a variety of other methods, including covering their crops to insulate them and even staying up all night to maintain small bonfires in their fields to keep the area warm. Seaman, whose small orchard grows specialty apples for local cider makers, says he is not able to make a large capital investment—like a heating system or greenhouse—and would like to explore less expensive options for frost protection. Seaman has tried coating his apple blossoms with ice and also has used fans to prevent the cold air from settling around the trees, but with minimal success.

Large investment or small, the questions still abound: How do farmers know when to light the fires or turn on the heaters or sprinklers? And for how long? Where is the best location for a fan to mix the air, and what other strategies could be used? The farmers would benefit from knowing which investments are most suited to their own farms and how best to use them—and this is where the scientists come in.



Plump peaches are a sign of success. Every spring, farmers in New Mexico worry that frosty nights might kill their trees' blossoms and eliminate the possibility of growing fruit, like these peaches at Freshies of New Mexico. Monitoring air temperature using the sensor shown here is one of the ways that Los Alamos scientists have been helping farmers optimize their strategies to protect crops from frost. PHOTO CREDIT: Michael Pierce

Plentiful data

The project began with Steinzig enlisting the help of hydrologist Kurt Solander and postdoctoral atmospheric scientist Tirtha Banerjee to look at the terrain of each farm and to try to understand what frost mitigation techniques would be possible. With help from plant physiologist

Sanna Sevanto, they also set up wired instrumentation around each farm to gather an assortment of data. However, the cost and difficulty of maintaining the instrumentation quickly became apparent as the scientists had to drive to the farms to manually download the data and the farmers found the wires to be both a tripping hazard and easily broken. A search began for a more cost-effective, networked, and self-sustaining data-gathering option. Goddard put his experience with wireless data sensors to work, and with renewed funding in 2018 and 2019, he worked with electrical engineering graduate student Josh Sackos to implement wireless sensors to remotely monitor a wide range of variables.

"It's not enough just to know the temperature," says Banerjee.

"There are a lot of factors at play that impact a plant's vulnerability to frost."

For one, when plants are dormant in the winter, they actually need the weather to get cold, a requirement referred to as "chill hours." Each plant requires a different temperature range and number of chill hours in order to flourish in the spring, and plants that don't get the appropriate amount are shown to be less robust against frosts. Moisture is also important; sufficient soil moisture and plant-tissue moisture are needed to help the plant resist damage.

With all of this in mind, the Los Alamos scientists set out to measure everything they could: air temperature, wind speed and direction, soil moisture, plant tissue temperature and moisture, relative humidity, and light availability. They also took into consideration the varied conditions at and around each individual farm and began to make recommendations to the farmers as soon as they could.

For instance, at Freshies, the scientists looked at the placement of the thermostat used to trigger the heating system within the greenhouses. Once they could identify which area got cold first, they recommended that Bassett move the thermostat to that particular spot so the heaters are triggered before the temperature drops to dangerous levels for crops within the greenhouse.

After analyzing temperature data with the heaters turned on for a couple of weeks, the team also recommended to Bassett that he adjust the heaters to start when the temperature reaches 32 degrees Fahrenheit instead of 30. This was done to provide more of a buffer against crop damage that occurs when temperatures drop below 28 degrees. However, Solander also explains that although the difference of a few degrees can cause a lot of damage, if the heaters go on too early or if heat is lost, it can waste energy, which can be prohibitively costly. To this end, the scientists determined the most vulnerable locations within the greenhouse, so that Bassett could address air leaks and circulation patterns within the structure of the greenhouse.

Because there are no greenhouses or heating systems at the Manzanar orchard, the Los Alamos team focused on understanding the impact of the local topography. Seaman had already pruned vegetation in an attempt to redirect cool air coming down from a nearby mesa in order to keep it away from the farm. Solander distributed sensors around the orchard and also used a drone to better understand the stratification of air temperatures over the area. The combined sensor and drone data characterized vertical and horizontal temperature gradients that were variable through time, and Solander hopes that more densely distributed and

When the trees are flowering, a 24-degree night results in 90 percent loss.

continuously monitored measurements in 2019 will help them refine conclusions about cold air mitigation.

To further understand the microclimate, the team used a Los Alamos-developed software tool called HIGRAD to model the airflow coming down from the mesa. Using atmospheric dynamics simulations, Banerjee suggests that they may be able to better understand the air mixing. Solander adds that by combining the modeled data with temperature measurements, they hope to simulate the efficacy of potential low-cost solutions, such as planting a row of 10–15-meter tall trees to act as a windbreak to protect the apple trees.

Seeking signal strength

Although the scientists have been able to make a few recommendations to the farmers thus far, one of the challenges the team has faced is a lack of consistency in data collection due to equipment malfunctions. In an effort to keep costs down, the team used off-the-shelf sensors that were each capable of sending data independently over a 3G cellular network for remote analysis. However, the cellular signal that worked with the sensors had intermittent coverage at the rural farms, and the data acquisition was spotty at best.

Fortunately, as the team began to investigate alternatives, a different kind of sensor became more widely available, and at a reasonable price. Using these new sensors, Sackos and Goddard established a platform for the 2019 season that works as a low-power wireless mesh network. With this network, the distributed sensors are connected to each other and to a central sensor that uses either Wi-Fi or LTE cellular signal to transmit the data to cloud-based storage. The data can then be pulled down into a database for analysis by Solander and Banerjee.

"We want to leave farms with an easy way to implement these hardware and software solutions in the future," explains Sackos. He says that by using commercially available hardware and open-source software, the system could be implemented at any farm. For instance, if a new farm were to join the program, the Los Alamos scientists could first help by analyzing the individual microclimate to provide recommendations about which mitigation strategies are appropriate (heaters,

We want to leave farms with an easy way to implement these solutions in the future.

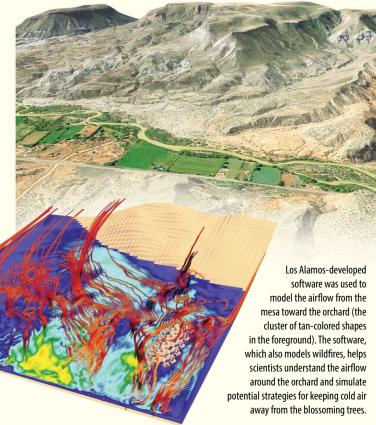
windbreaks, etc.). Once in place, a farmer could invest in sensors to connect to an entire regional network of farms, all working together to help track impending frost conditions, which could enable alerts to be sent when the temperature hits a critical point.

As word has spread about the network, interest in the project has grown. A third farmer, Sam Starsiak from the Diamond Sow farm in Truchas, New Mexico, has already requested support in monitoring soil moisture, and others are lining up.

Love locally grown

Using technology to help warn about or mitigate frost damage could have an immediate benefit for local farms in Northern New Mexico. Banerjee explains that this kind of data collection and intervention, or "smart agriculture," is becoming more and more common

The Manzanar Los Silvestres apple orchard is nestled against the Rio Chama river near the town of Abiquiu. It is a difficult place to grow apples in part because of cold air flowing down from the neighboring mesa. IMAGE CREDIT: Google, Landsat / Copernicus



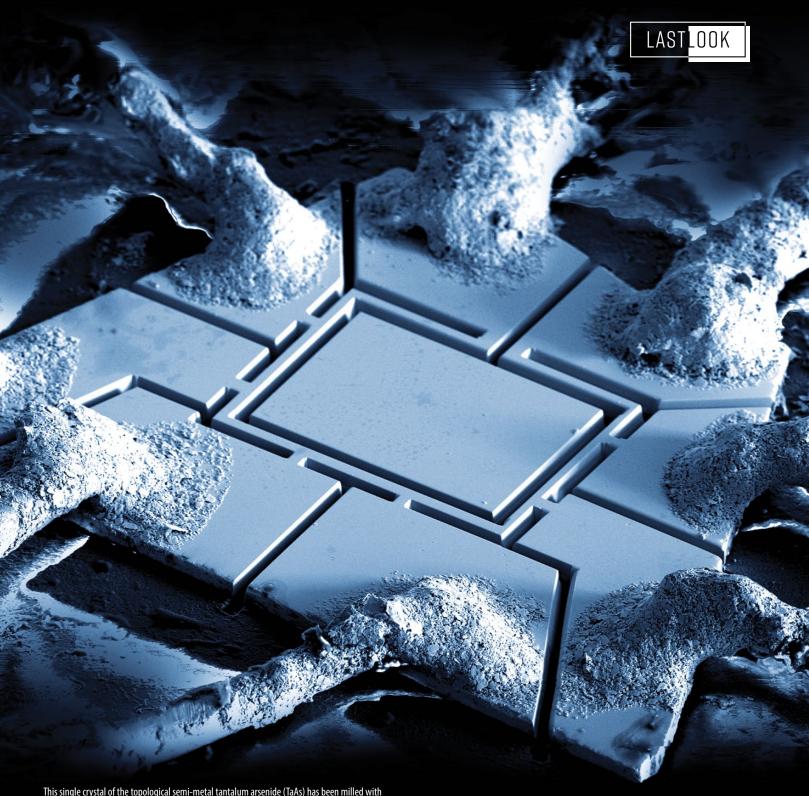
with industrial agriculture, but at a hefty price. He hopes that the Los Alamos-NMSBA approach to helping smaller farms with less-expensive alternatives will keep them competitive, thus strengthening local agriculture as a whole. But for the farmers and consumers, the state economy isn't the only reason to support local produce.

"I came to farming through food. I was captivated by how good fresh food can taste," says Bassett.

Bassett explains that when fruits and vegetables are transported long distances between farm and grocery store, they have to be picked before they are ripe and sometimes stored for long periods of time. Allowing food to ripen "on the vine" allows it to develop and retain a significant amount of flavor and nutrients. Local food also has a smaller impact on the environment compared to industrial agriculture where fossil fuel-based synthetic fertilizers and agrochemicals are commonplace and fossil fuels are used to operate farm machinery and transport food long distances.

For these reasons, Bassett and Seaman provide a wide variety of fruits and vegetables to nearby stores and restaurants. They also sell their goods directly to customers at regional farmers' markets. And even as the growing season shifts, they'd like to keep their produce the same as it has always been: fresh, sustainable, and local.

-Rebecca McDonald



This single crystal of the topological semi-metal tantalum arsenide (TaAs) has been milled with a pattern of channels using a gallium focused ion beam (FIB) microscope. The sandpile-like lumps are silver epoxy, which provides electrical contact to ultrathin wires—each thinner than a human hair. The channels define the current path and enable conductivity along different crystallographic directions to be simultaneously measured with significantly enhanced fidelity in the world's highest nondestructive magnetic fields. These measurements help reveal how the flow of electrons in TaAs differs from that in conventional metals.

FIB microscopy is a capability used by materials scientists across the Laboratory. This year, Los Alamos plans to invest in a next-generation electron and ion beam microscope, using a xenon plasma instead of the gallium-ion column. Among other advances, this new microscope will enable higher cut rates and finer structures to be machined, while eliminating the risk of gallium contamination. CREDIT: Ross McDonald/LANL

ISSN: 1942-6631



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Mail Stop M711 Los Alamos National Laboratory P.O. Box 1663 Los Alamos, NM 87545

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U.S. highway 64 crosses over the Rio Grande Gorge, an 800-foot chasm west of Taos, New Mexico. The gorge boasts hiking and biking trails, ancient petroglyphs, natural hot springs, and whitewater rafting.



